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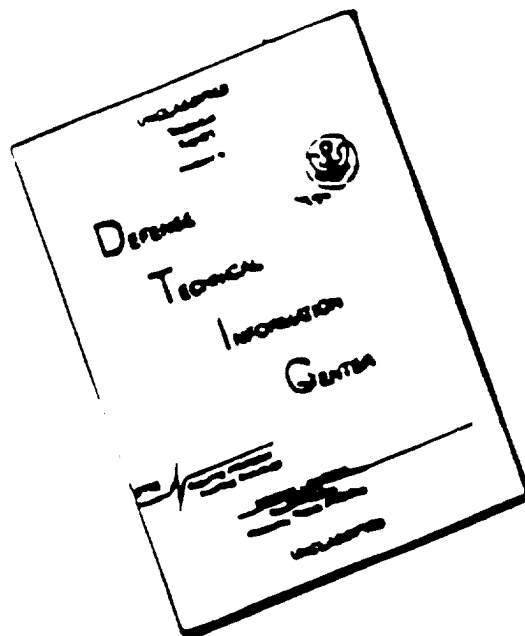
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STUDY OF THE RELATIONSHIP BETWEEN CORONAL MASS EJECTIONS AND ENERGETIC ELECTRONS IN INTERPLANETARY SPACE

E. I. Daibog, S. W. Kahler, V. G. Stolpovskii

We consider time characteristics of energetic electron events in interplanetary space after solar flares associated with coronal mass ejections (CME). Analysis of electron intensity–time profiles shows that independently of flare duration times to electron event maximum from flare onset and from electron event onset increase with increasing of CME velocity. Possible interpretation of this effect is electron acceleration by CME associated shock wave.

1. INTRODUCTION

An important problem of solar energetic particle (SEP) events is whether SEPs are accelerated in impulsive phase of a flare or by coronal and interplanetary shocks associated with CMEs (Coronal Mass Ejection). As a whole particle acceleration by shocks is widespread phenomenon in the heliosphere and many astrophysical objects [1]. Some time ago it has been recognized that shocks are of fundamental importance for SEP events [2, 3].

As for observations of shock accelerated particles there are clear evidencies and identifications of shock particle enhancements at energies of hundreds keV–MeVs for protons and up to tens keV for electrons [4]. Situation with energetic electrons ($E > 0.1$ MeV) is not so transparent. Energetic electrons can easily escape from the shock front and their motion has another time as well as length scales. Moreover they can go away and greatly outstrip a shock front.

The majority of observations both at low and high energies concerns proton events. Direct detailed measurements of energetic electron component of SEPs are less numerous and its relation to shocks is known much worse than in a proton case. The main ideas on accelerated electron dynamics in a source and solar atmosphere were obtained using solar X- and radioemission observations and are extremely model-dependent. Their application to electron events in interplanetary space gives ambiguous results. So better understanding of an interrelation between energetic electron fluxes and shocks may be achieved when results of direct electron measurements and data of X- and radioemission observations are considered together. But such investigations are not numerous.

There are both pro and contra arguments for shock subrelativistic and relativistic electron acceleration. Observations of energetic electron events lasting for many hours following large flares [5], electron events without hard X-ray association [6] and other arguments [7] can be supports of the point of view, that energetic electrons were accelerated in long duration process and a shock source is a possible explanation for these events. However up to now the contribution to interplanetary electron fluxes from acceleration in coronal or interplanetary shocks is poorly understood.

In [7] we studied a probaibility of shock acceleration of > 70 keV electrons. If these electrons in SEP events can arise from either flares or shocks, then we should expect that the electron escape efficiency should be different for flares with and without CME. We estimated an escape efficiency comparing maximum electron flux with hard X-emission fluence and found that it is some higher (by factor of 2) in the case of flares associated with CME. It may be considered that the shock electron population is comparable to that of impulsive component. But statistics was not rich enough and only well-connected events were taken into account. So the conclusion must be cleared up.

In the present paper we examine the association and timing of flares and CMEs for a sample of 24 SEP events observed by ISEE 3 from 1980 through 1985. We examine the intensity-time pofiles of electron enhancements to see if there is any distinction in profile shape in the cases of flares with and without CMEs. In [8] we have considered > 0.3 MeV electron intensity-time profiles in SEP events according to Helios data from 1979 through 1982. It was assumed that if an acceleration occurs during an extended period of shock propagation in corona then time interval for which SEP intensity rises to the maximum will be longer in comparison with acceleration in impulsive phase of a flare. We established that on the average rise time of electron enhancements related to flares with CMEs is really some longer. But statistics was not high. We shall compare relations between flare, CME and electron enhancement parameters obtained for a sample of ISEE 3 events with those ones from Helios and Phobos 2 observations [8, 9]. In a number of cases the same SEP events were observed by Helios, ISEE 3 and Venera.

2. DATA SOURCE AND PROCESSING METHODS

Data considered includes an information on SEP events, flares and CMEs. Energetic particle fluxes were measured onboard ISEE 3 which was in the inner Lagrangian point between Sun and the Earth. Electrons with energy between 0.22 and 2.0 MeV and 4–19 MeV were measured in the GSFC medium–energy cosmic ray experiment. Time resolution of electron measurements was high enough and we used 15 min averaged data in our investigation in according to [10].

Standard information about H_α-flares and bursts of flare in hard X- and radioemission was taken from Solar–Geophysical Data and from Internet network. In the case of electromagnetic bursts we used not only table data but also intensity–time plots. An information on corresponding hard X–bursts was provided by HXRBS observations on SMM [11].

During the periods considered CMEs were observed by the Solwind coronagraph on P78-1 at distance from 2.5 $R_\odot$ to 10 $R_\odot$ and coronagraph/polarimeter on SMM. Data of Solwind observations were prepared by N. R. Sheeley [12]. In the case of SMM observations we have a revised and expanded catalogue [13] which permits us to obtain time, velocity, position angle and other parameters of CMEs associated with selected SEP events.

Selection of electron events was made on the basis of energetic electron intensity–time variations. Sharp intensity rise, followed by more or less gradual decay of electron flux was considered as SEP event. Those enhancements having duration more than 3 hours and amplitude execeeding the background by 3σ were taken into account. According to 3σ condition we could distinguish electron enhancements with the amplitude of > 0.2 MeV electron flux greater than 0.05 particle/cm^2 sec sr.

The particle source identifications for the majority of SEP events considered have been published previously. We began, however, by making flare/CME associations without reference to these previous studies. We used standard method of identification of parent flare [14]. The associations derived were essentially the same as those arrived in earlier studies. But our event list contains a number of smaller events which were not included in previous lists.

The observer's magnetic footpoint was determined by the method described in [15], taking into account the real solar wind velocity. For recalculating times of electron intensity maximum from one angular distance between magnetic footpoint and flare site to another one it's necessary to employ some model notions. We used ideas of simple diffusion model and took into account a difference of angular distances. Here we used formalism of coronal propagation [16] which is supposed to be independent of the physical content of phenomena considered. So we used approximation formulae for coronal propagation of > 0.5 MeV electrons from [17] and recalculated them to 0.2 MeV. A fit to the data was performed by assuming that the constant delay within certain angular distance $\varphi_0 = 26$ (Fast Propagation Region) is due to interplanetary propagation and that time to maximum tm increases linearly beyond φ_0. Then may be aproximated by the next formula.

$$t_m(1\ \mathrm{AU}, \varphi) = 78 + 4.1(\varphi - 26)\ ,\ \mathrm{min} \qquad (1)$$

where the first and the second terms describe interplanetary to $r = 1$ AU and coronal propagation, respectively.

We suppose that there must be some correlation between rise time of SEP event and a velocity of coronal shock. Let us suppose for simplicity that CME

velocity is changing with constant acceleration and CME driven shock can accelerate electrons if shock velocity is higher than some V_{lim}. Let the CME speed rises till the value V_0. Then the time during which electrons should be shock accelerated increases with increasing Vo and a distance that shock travels during this time also increases with increasing V_0. In a case of constant CME and shock speed distance at which shock can accelerate particles, would be traveled by the shock in a time decreasing with increase of V_0. As a mattter of fact it is necessary to take into account damping of shock and decreasing of ambient plasma density but as a whole the character of V_0 vs t dependence would be the same: $t(V_0)$ — decreasing function, if $V = V_0 = $ const, and $t(V_0)$ — increasing function, if CME acceleration or deceleration takes place.

So as we know about acceleration — deceleration of the shock, we are waiting as a result of our investigation that rise time of SEP event is increasing function of CME traveling speed, because the injection continues for longer times with faster CMEs, and a size of injection region increases faster than linearly with CME speed. Preliminary investigation [8] showed that there is a tendency of increasing rise time vs CME speed.

If the cone containing CME intersects with limb plane then measured CME velocity is the real one. If not, we obtain the "real" CME velocity by recalculation of the nearest to the sky plane forming of the CME cone. Recalculated V_{CME} is

$$V_{calc} = V_{CME} / \cos(\xi - \alpha/2) , \qquad (2)$$

where ξ is an angle between radial flare extension and the sky plane,

$$\xi = \arccos\left[\cos^2\theta \cdot \sin^2 B + \sin^2\theta\right]^{1/2} . \qquad (3)$$

Angle α in (2) is a real dimension of CME cone,

$$\alpha = 2\operatorname{arctg}\left[\operatorname{tg}(D/2)\cdot\cos\xi\right] , \qquad (4)$$

angle D is dimension of CME cone in the sky plane.

4. RESULTS AND DISCUSSION

ISEE data list includes 24 events obtained at 1 AU and is shown in the table.

Here "1" is event number; "2"— event date; "3" — flare location; "4" — CME initial position angle and width (in parenthesies); "5" — CME velocity, km/s; "6" — CME velocity, calculated according to (2), km/s; "7" — angular distance φ; FPR means that observation point is projected to fast propagation region; "8" — time to maximum of electron event corrected accoding to (1), hrs; "9" — electron event rise time, hrs; time, hrs; "10" — soft X-rays duration (L — long, > 1 hour, S — short, < 1 hour).

| 1	2	3	4	5	6	7	8	9	10
1	040480	N27W34	N07W(140)	840	840	FPR	3.0	2.1	L
2	070680	N13W70	no			FPR	1.2	1.0	S
3	070680	N14W70	no			FPR	0.8	0.6	S
4	230381	N10W54	N30W(40)	400	420	FPR	1.7	1.0	S
5	250381	N09W87	N25W(70)	900	900	W50	2.5	2.0	S
6	300381	N13W72	N10W(180)	1300	1300	FPR	2.0	1.0	L
7	040481	S44W87	S45W(35)	900	900	W40	3.6	2.5	S
8	280481	N16W90	N05W(30)	1000	1000	W48	3.2	3.0	L
9	071181	S10W39	no			FPR	1.3	0.8	S
10	141181	N16W49	N05W(110)	585	615	FPR	4.6	4.5	L
11	051281	N20W40	N45W(60)	840	905	FPR	6.5	5.5	L
12	020182	N19W88	N10W(40)	650	650	W45	2.0	1.0	S
13	080282	S13W88	N05W(10)	1310	1310	FPR	1.3	1.1	S
14	090282	S14W90	N05W(30)	1600	1600	W33	1.5	1.6	S
15	070382	N19W53	N10W(60)	1140	1240	FPR	2.9	2.4	L
16	190782	N21W45	N45W(40)	630	700	FPR	1.8	1.5	S
17	080882	S09W65	S10W(10)	600	640	FPR	3.0	2.0	S
18	130882	N11W59	S30W(20)	300	330	FPR	0.8	0.6	S
19	140882	N11W63	no			FPR	1.0	0.7	S
20	221182	S08W34				FPR	1.6	1.3	S
21	221182	S11W36	S10W(60)	740	805	FPR	3.1	2.7	L
22	071282	S19W86	S10W(20)	1250	1250	FPR	3.4	2.5	L
23	050183	>W90	no			FPR	1.7	1.0	S
24	150583	S10W80	S25W(50)	1110	1110	FPR	2.5	1.0	S

Рис. 1.

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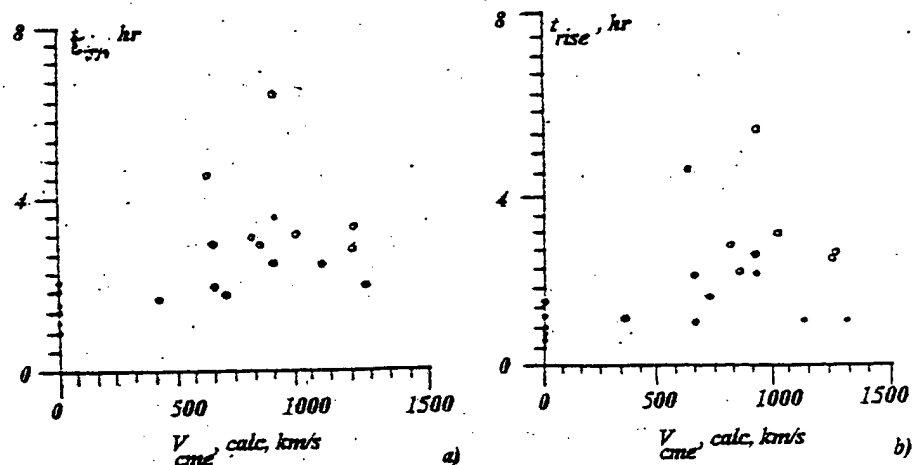
In Fig. 1 we present time to maximum (a) and rise time (b) vs calculated V_{cme}. Events NN 13, 14 and 18 of the table were excluded from the figure as the corresponding flares were in opposite hemispheres with observed CMEs. Two points with highest values of t_m and t_{rise} concern NN 10 and 11 events. We compared these values with t_m and t_{rise} obtained by Helios and Venera observations [6, 7]. In the case of Nov. 14, 1981 event Venera was near the Earth and values t_m and t_{rise} were 4.2 hrs and 4.0 hrs, respectively. For Dec. 5, 1981 event Helios and Venera were located at $r = 0.95$ AU and $r = 0.44$ AU, respectively. Venera's magnetic footpoint was in FPR, angular distance for Helios was E95. Normalized values t_m were 7.0 and 8.1 hrs for Venera and Helios, respectively. Thus high values of t_m and t_{rise} obtained in three different points are practically the same. It seems that these events are related to disturbances which could be caused by filament dissapearance. For Dec. 5, 1981 it was proved in [18]. It confirms that energetic electrons can be accelerated by CME driven shock.

We see from Fig. 1 that t_m and t_{rise} are slowly increasing with increasing V_{CME} and that all values of t_m and t_{rise} are less for non-CME associated flares than for CME-associated ones. Open circles are for L, dark points — for S events. As there is no difference between L and S events in Fig. 1 one may conclude that t_m and t_{rise} are caused rather by time extended shock acceleration than by flare duration.

REFERENCES

1. Johnson F. C., Elisson D. C. // Space Sci. Rev. 1991. V. 58. P. 259.

2. Evenson P. A., Meyer P., Yanagita S. // J. Geophys. Res. 1982. V. 87. P. 625.

3. Cane H. V., Reams D. V., Von Rosenving T. // J. Geophys. Res. 1988. V. 93. P. 9555.

4. Krimigis S. M. // Space Sci. Rev. 1992. V. 59. P. 83.

5. Lin R. P. // Solar Phys. 1985. V. 100. P. 537.

6. Daibog E. I., Kurt V. G., Logachev Yu. I., Stolpovskii V. G. // Kosm. Issled. 1989. V. 27. P. 113.

7. Kahler S. W., Daibog E. I., Kurt V. G., Stolpovskii V. G. // Ap. J. 1994. V. 422. P. 394.

8. Kahler S. W., Stolpovskii V. G., Daibog E. I // IAU Colloq. 1994. P. 479.

9. Stolpovskii V. G., Erdos G. et al. // Proc. 24th Int. Cosm. Ray Conf. 1995. V. 4. P. 301.

10. Richardson I. // private communication.

11. Dennis B. R. et al. // NASA TM–4332, 1991.
12. Sheeley N. R., Jr. // private communication.
13. Burkepile J. T., St. Cyr O. C. // NCAR/TN–369+STR, 1993.
14. van Hollebecke M. A. I. et al // Solar Phys. 1975. V. 41. P. 189.
15. Notle J. T., Roelof E. C. // Solar Phys. 1973. V. 33. P. 241.
16. Lin R. P., Mewaldt R. A., van Hollebeke M. A. L. // Ap. J. 1982. V. 253. P. 949.
17. Kahler S. W. et al. // Ap. J. 1986. V. 502. P. 504.

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